5.0 TECHNICAL ISSUES

5.1 AUTHORITIES REVIEW TEAM ISSUES AND ACTION

The ARAC Tasking required that a team of technical experts from the regulators review the technical program, developed by the AAWG. The purpose of this review was to validate the approach adopted by the AAWG. This review occurred in the March 1998 Gatwick UK meeting. The team, hereafter known as The Authorities Review Team, or ART, consisted of:

John Bristow, Chair	CAA-UK
Bob Eastin	NRS Fatigue and Fracture, FAA
Brent Bandley	Aerospace Engineer, FAA
Stephane Boussu	DGAC - France

The ART reviewed the approach of the AAWG with respect to the tasking as well as presentations on OEM methodologies. John Bristow, chair, expressed his thanks for participation of the AAWG-TPG at the ART Review. He expressed that while there were certain things that needed to be addressed, the ART felt that the team was properly composed and heading in the right direction.

The ART did find areas within the scope of the program that they needed further development from both a regulatory and a technical viewpoint. A total of twenty issues were presented to the AAWG for resolution. The AAWG evaluated each of the issues and then assigned action to resolve each issue. The following table delineates the issues and actions that were assigned and completed.

ITEM	ISSUE	Final Report Section
1	The ART would like to see a more immediate focus on validation of OEM methodologies through round-robins etc. and a defocus of R&D review.	8.6
2	The ART would like to see more information related to residual strength testing related to WFD.	Sec 6.1.5
3	The ART would like an explanation of Objective Evidence specifically what the meaning of Qualitative vs. Quantitative is.	Explain at next review
4	The ART believes that there is sufficient data available to determine the state of the fleet WRT MSD/MED. For example, the ART wants the AAWG to review SDR data in coming to conclusions regarding the health of the fleet.	7.0
5	The ART would like to see more real-life examples.	7.0
6	The ART wants more information on STCs and how the issue might be addressed.	5.6
7	The ART does not understand the issue of Restraints in getting fleet data.	7.0

ITEM	ISSUE	Final Report Section
8	The ART would like the establishment of a baseline detectable flaw to consider in-service constraints including the requirement of wide area inspections and would like that information by the end of April 1998.	6.2
9	The ART wants more information WRT the DPD presentation on monitoring period.	4.4
10	The ART needs justification for the removal of discrete source damage.	5.3
11	The ART feels that if the existing maintenance program is adequate to detect MSD/MED, then that program should be mandated.	4.1
12	The ART will look for a recommendation on how to overcome the shortfall in technology.	6.0
13	The ART will require a consistent usage of terminology and definitions by the AAWG	4.3
14	The ART will need a significantly higher level of technical presentation at the next review.	Agreed
15	The ART desires to see on a fleet by fleet basis, timelines delineating when the analysis is complete, when the changes to the maintenance programs (e.g. mandatory mods, SSID changes etc.) will be complete, and when the programs need be implemented in the fleet.	9.0/10.0
16	The ART will require a revisit to the at risk fleets. They feel freighters need to be included, the logic behind the division at 1/2 DSG is not clear (needs to be supported by fleet evidence), and that there may be other airplanes needed in priority 2 by virtue of derivative design. They would also like to see the number of airplanes exceeding 100% DSG and the actual DSG for each Aircraft fleet.	Table 9.1
17	The ART requires additional information regarding Step 1.1 of The Airplane Evaluation Process . They would like additional definitions developed and an additional step added.	Figure 1.1
18	The ART would like to understand how allowable lead times for modifications are established.	9.2
19	The ART needs additional data WRT how life limits would be imposed and how the handling of a non-compliance action occurs.	10.0
20	While the ART concurs that the monitoring period is an appropriate means to work this problem, the developments of appropriate constraints are necessary to make the approach viable.	4.4

The Report Section numbers refer to where the issues are discussed in detail.

5.2 AREAS SUSCEPTIBLE TO MSD/MED

Susceptible structure is defined as that which has the potential to develop MSD/MED. This structure has the characteristics of similar details operating at similar stress levels where structural capability could be significantly degraded by the presence of multiple cracks.

Figures 5.1 through 5.16 illustrate major sections of airplane structure, and construction typical of those areas, which industry experience has shown to be susceptible to MSD/MED. The illustrations shown are typical and do not show all types of construction or structural details, which may be peculiar to an airplane model. Some model specific examples may be best illustrated by a combination of these examples. Additional areas of the model specific structure should be assessed if indicated by service or test experience.

MSD and/or MED can also occur in structure that does not have a major impact on the continued safe operation of an airplane. For example MSD cracking of a web adjacent to a stiffener may not be any more significant than a single fatigue crack. Also, it is not expected that secondary structure will be included in the WFD assessment.

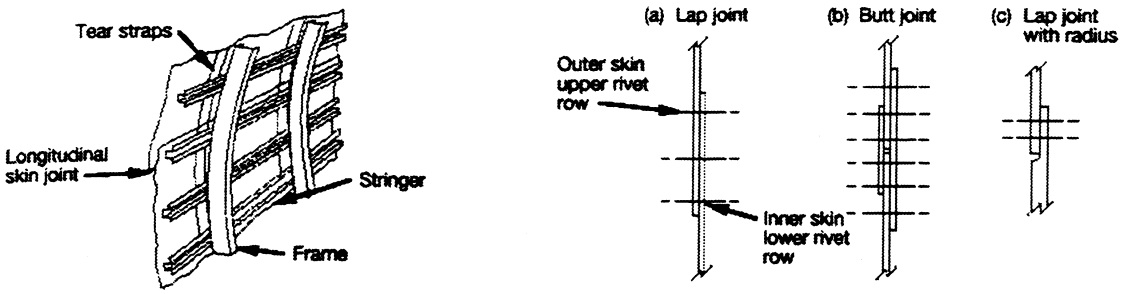
Susceptible areas are characterized by similar structural details operating at uniform stress levels. There are many significant structural problems that can occur in airplane structure due to fatigue cracking but they typically <u>are not</u> precursive forms WFD. Examples are:

- CHRONIC INSERVICE FATIGUE PROBLEMS, which left undetected or uncorrected, could lead to a significant failure.
- MULTIPLE PARALLEL CRACKS which grow parallel to each other and do not have the potential to link-up
- ELEMENTS IN COMMON such as a fuselage bulkhead (skin, web, and cap) or a wing spar (skin, cap, and web). Fatigue cracking of a single element if left undetected or uncorrected can ultimately lead to fatigue cracking of all three elements at a common location. Service actions and AD s should be adequate.
- LINK-UP OF INDEPENDENT FATIGUE PROBLEMS in adjacent but not similar structural elements (not MED) can grow, if not corrected, until they link-up resulting in a very significant loss in residual strength. STG service action review should mandate corrective action.

The priority to be assigned to each susceptible structural item to be evaluated for widespread fatigue damage will be dependent upon the individual airplane model. The OEM or STC holder should assess these properties for each airplane model on the basis of in-service experience, test and/or analysis. It is recommended that this survey be performed at the start of the evaluation.

The list of structure potentially susceptible to MSD/MED first appeared in the 1993 report of the Industry Committee on Widespread Fatigue Damage. Additional areas and details have been added as a result of further review of service experience. Additionally, details of crack locations have been clarified.

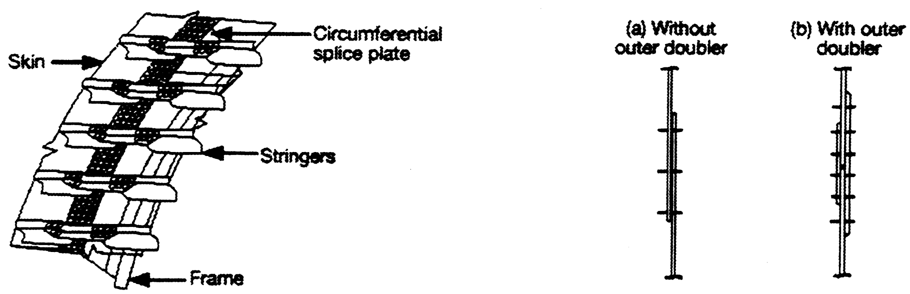
STRUCTURAL AREA	FIGURE
• Longitudinal Skin Joints, Frames, and Tear Straps (MSD/MED)	5.1
• Circumferential Joints and Stringers (MSD/MED)	5.2
• Lap joints with Milled, Chem-milled or Bonded Radius (MSD)	5.3
• Fuselage Frames (MED)	5.4
• Stringer to Frame Attachments (MED)	5.5
• Shear Clip End Fasteners on Shear Tied Fuselage Frames (MSD/MED)	5.6
• Aft Pressure Dome Outer Ring and Dome Web Splices (MSD/MED)	5.7
• Skin Splice at Aft Pressure Bulkhead (MSD)	5.8
• Abrupt Changes in Web or Skin Thickness Pressurized or Unpressurized Structure (MSD/MED)	5.9
• Window Surround Structure (MSD, MED)	5.10
• Over Wing Fuselage Attachments (MED)	5.11
• Latches and Hinges of Non-plug Doors (MSD/MED)	5.12
• Skin at Runout of Large Doubler (MSD) Fuselage, Wing or Emp	5.13
• Wing or Empennage Chordwise Splices (MSD/MED)	5.14
• Rib to Skin Attachments (MSD/MED)	5.15
• Typical Wing and Empennage Construction (MSD/MED)	5.16



Type and possible location of MSD and MED
- MSD longitudinal skin joint
  - Lap joint
    - Outer skin upper rivet row
    - Inner skin lower rivet row
  - Butt joint
    - Skin outer rivet rows
    - Doubler inner rivet rows
  - Lap joint with radius
    - In radius
- MED—frame
  - Stress concentration areas
- MED—tear straps
  - Critical fastener rows in the skin at tear strap joint

Service or test experience of factors that influence MSD and MED (examples)
- High stress—misuse of data from coupon test
- Corrosion
- Disbond
- Manufacturing defect
  - Surface preparation
  - Bond laminate too thin
  - Countersink, fastener fit
- Design defect—surface preparation process

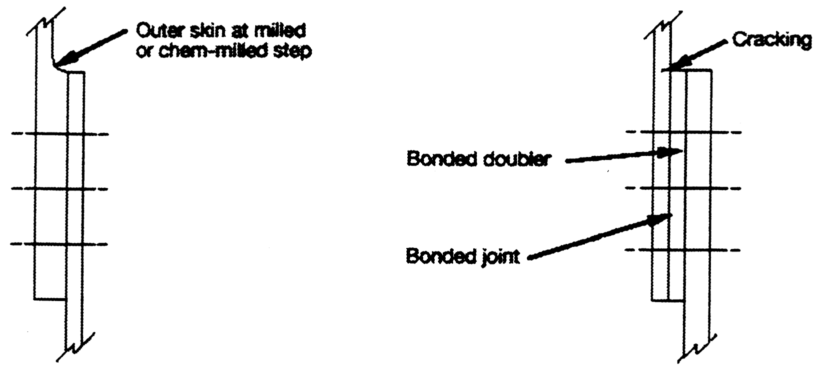
Figure 5.1 Longitudinal Skin Joints, Frames, and Tear Straps (MSD/MED)



Type and possible location of MSD/MED
- MSD—circumferential joint
  - Without outer doubler
    - Splice plate—between and/or at the inner two rivet rows
    - Skin—forward and aft rivet row of splice plate
    - Skin—at first fastener of stringer coupling
  - With outer doubler
    - Skin—outer rivet rows
    - Splice plate/outer doubler—inner rivet rows
  - MED—stringer/stringer couplings
    - Stringer—at first fastener of stringer coupling
    - Stringer coupling—in splice plate area

Service or test experience of factors that influence MSD and/or MED (examples)
- High secondary bending
- High stress level in splice plate and joining stringers (misuse of data from coupon test)
- Poor design (wrong material)
- Underdesign (over-estimation of interference fit fasteners)

Figure 5.2 Circumferential Joints and Stringers (MSD/MED)



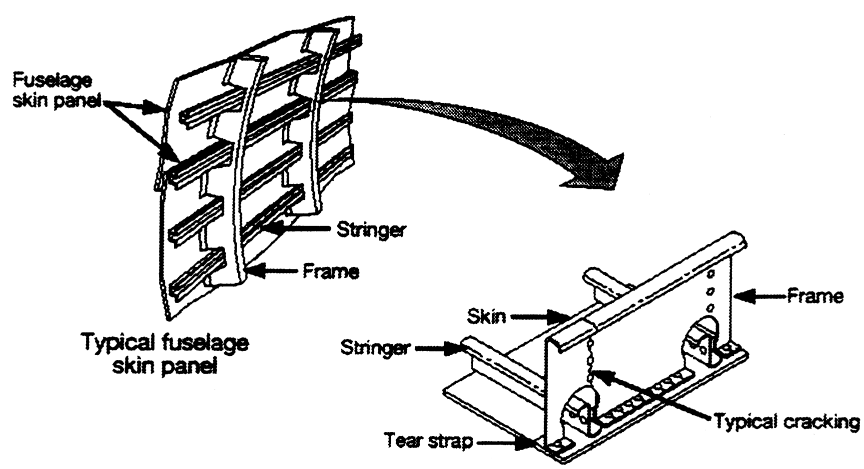
Type and possible location of MSD and MED

- MSD—abrupt cross section change
- Milled radius
- Chem-milled radius
- Bonded doubler runout

Service or test experience of factors that influence MSD and MED (examples)

- High bending stresses due to eccentricity

Figure 5.3 Lap joints with Milled, Chem-milled or Bonded Radius (MSD)



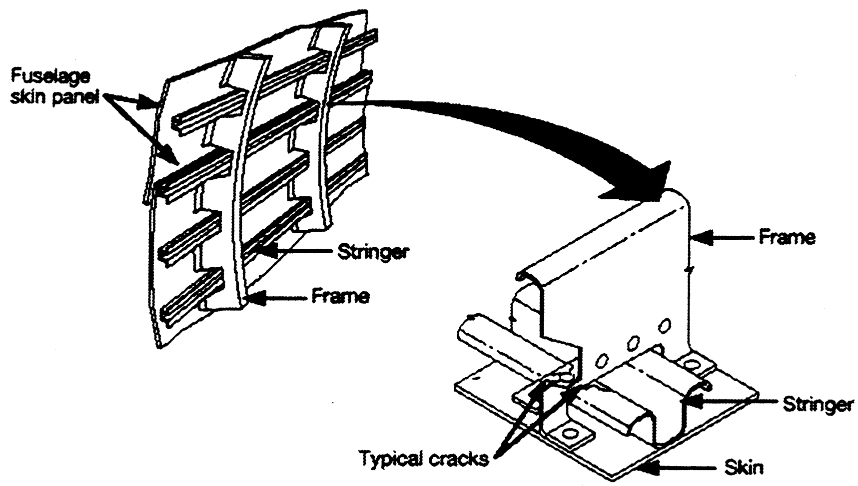
Type and possible location of MSD/MED

- MED—the cracking of frames at stringer cutouts at successive longitudinal locations in the fuselage. The primary concern is for those areas where noncircular frames exist in the fuselage structure. Fractures in those areas would result in panel instability.

Service or test experience of factors that influence MSD and/or MED (examples)

- High bending—noncircular frames
- Local stress concentrations
  - Cutouts
  - Shear attachments

Figure 5.4 Fuselage Frames (MED)



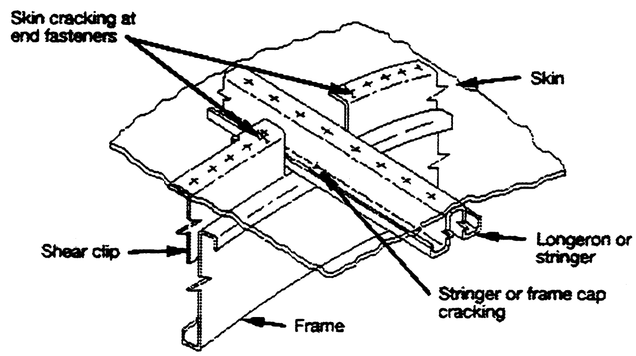
Type and possible location of MED

- MED—any combination of fracture of frames, clips, or stringers, including the attachments, resulting in the loss of the shear tie between the frame and stringer. This condition may occur at either circumferential or longitudinal locations at fuselage frame/stringer intersection.

Service or test experience of factors that influence MSD and/or MED (examples)

- Poor load path connection

Figure 5.5 Stringer to Frame Attachments (MED)



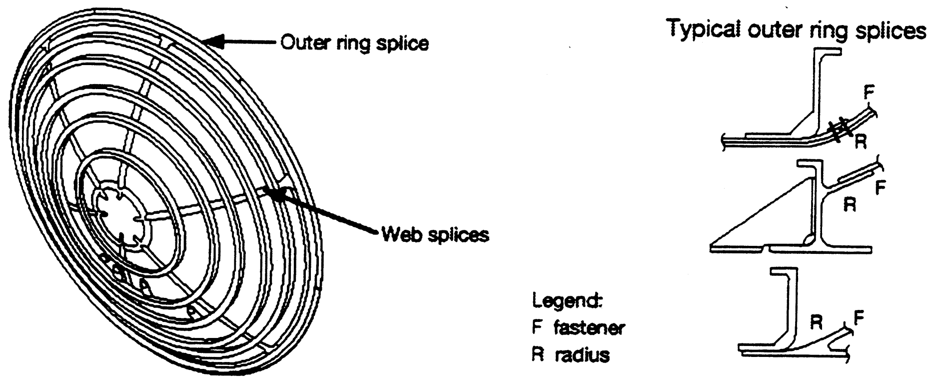
Type and possible location of MSD and MED

- MSD—skin at end fastener of shear clip
- MED—cracking in stringer or longeron at frame attachment
- MED—cracking in frame at stringer or longeron attachment

Service or test experience of factors that influence MSD and MED (examples)

- Preload
- Localized bending due to pressure
- Discontinuous load path

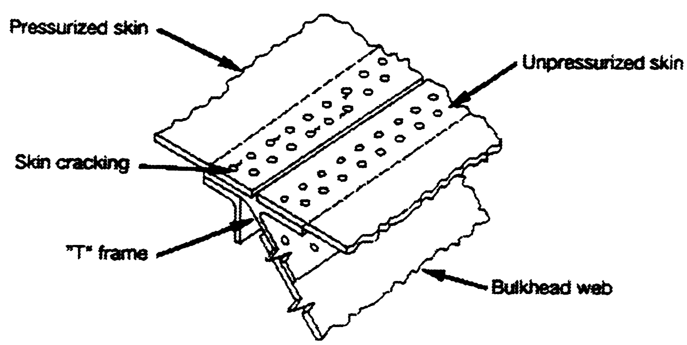
Figure 5.6 Shear Clip End Fasteners on Shear Tied Fuselage Frame (MSD/MED)



Type and possible location of MSD/MED
- MSD/MED—outer ring splice
  - Attachment profiles—at fastener rows and/or in radius area
- MED—web splices
  - Bulkhead skin and/or splice plates—at critical fastener rows

Service or test experience of factors that influence MSD and/or MED (examples)
- Corrosion
- High stresses—combined tension and compression
- High induced bending in radius
- Inadequate finish in radius—surface roughness

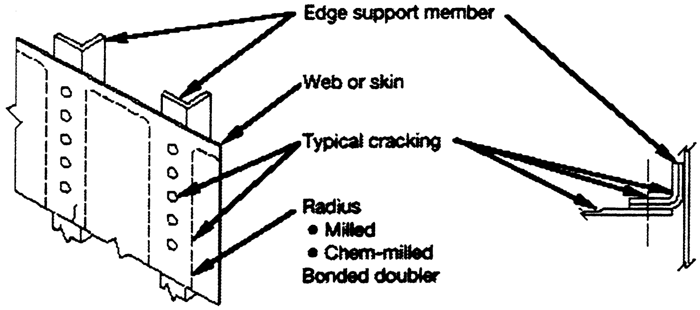
Figure 5.7 Aft Pressure Dome Outer Ring and Dome Web Splices (MSD/MED)



Type and possible location of MSD and MED
- MSD—skin at end fastener holes

Service or test experience of factors that influence MSD and MED (examples)
- Shell discontinuous induced bending stresses
- High load transfer at fastener

Figure 5.8 Skin Splice at Aft Pressure Bulkhead (MSD)



Type and possible location of MSD and MED

Abrupt change in stiffness*
- Milled radius
- Chem-milled radius
- Bonded doubler
- Fastener row at edge support members

Edge member support structure
- Edge member - in radius areas

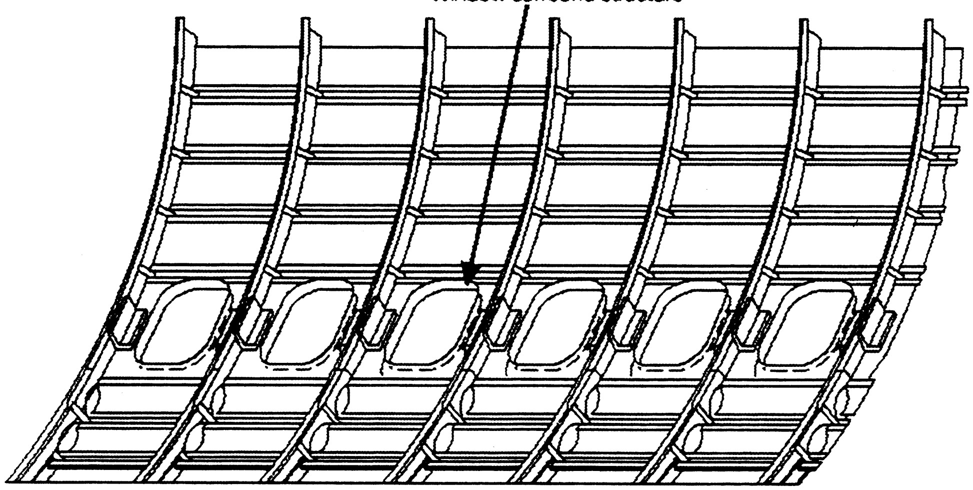
Service or test experience of factors that influence MSD and MED

Pressure structure
- High bending stresses at edge support due to pressure

Non-pressure structure
- Structural deflections cause high stresses at edge supports

* Often multiple origins along edge member

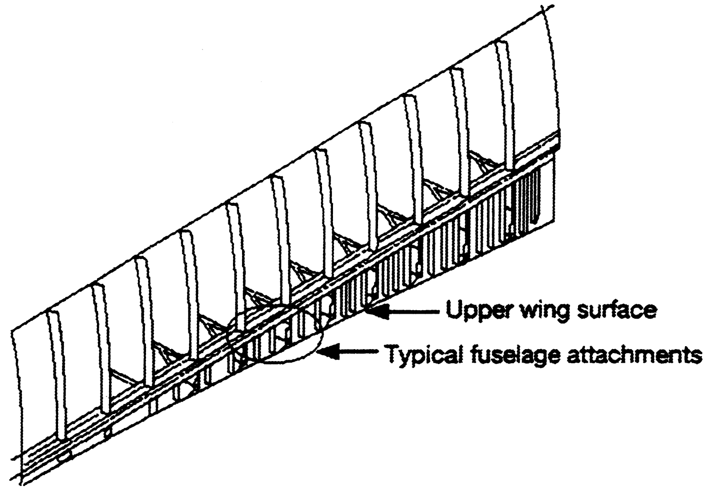
Figure 5.9 Abrupt Changes in Web or Skin Thickness Pressurized or Unpressurized Structure (MSD/MED)



Type and possible location of MSD/MED
- MSD—skin at attachment to window surround structure
- MED—repeated details in reinforcement of window cutouts or in window corners

Service or test experience of factors that influence MSD and/or MED (examples)
- High load transfer

Figure 5.10 Window Surround Structure (MSD, MED)



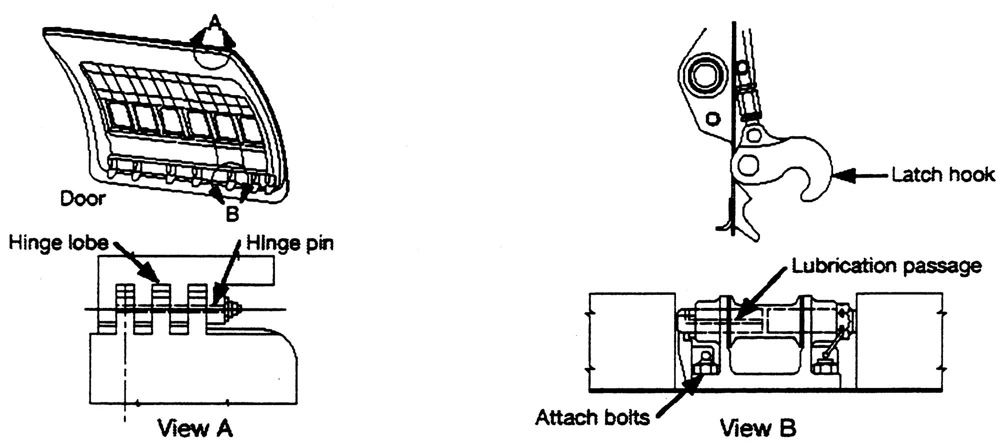
Type and possible location of MSD/MED

- MED—repeated details in overwing fuselage attachments

Service or test experience of factors that influence MSD and/or MED (examples)

- Manufacturing defect—prestress
- Induced deflections

Figure 5.11 Over Wing Fuselage Attachments (MED)



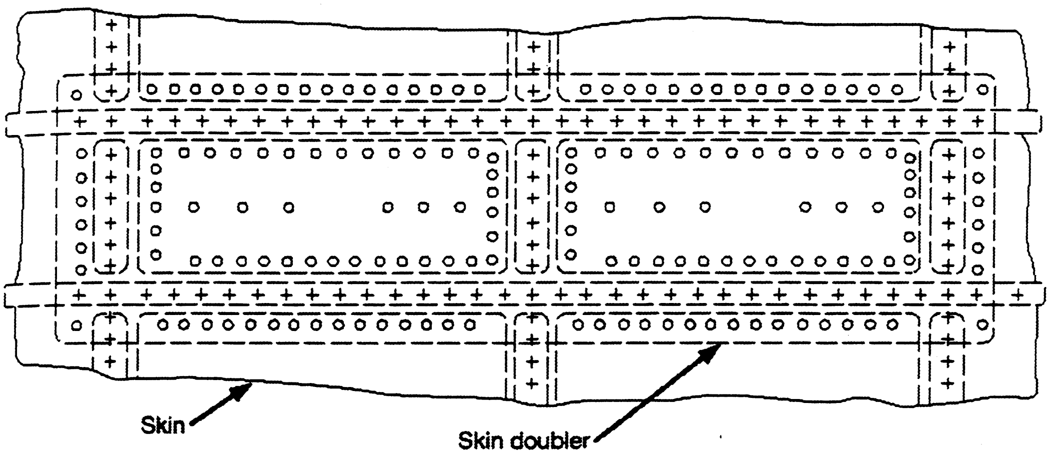
Type and possible location of MSD/MED

- MSD—piano hinge
  - At hinge fastener attachment row
  - In fillet radius
  - Emanating from hole in lobes
- MED—latches
  - In multiple latch hooks
  - At lube channel of latch spool
  - At spool bracket attach bolts (also corrosion)

Service or test experience of factors that influence MSD and/or MED (examples)

- Bending stresses due to fuselage elongation
- High local stress
- Fretting

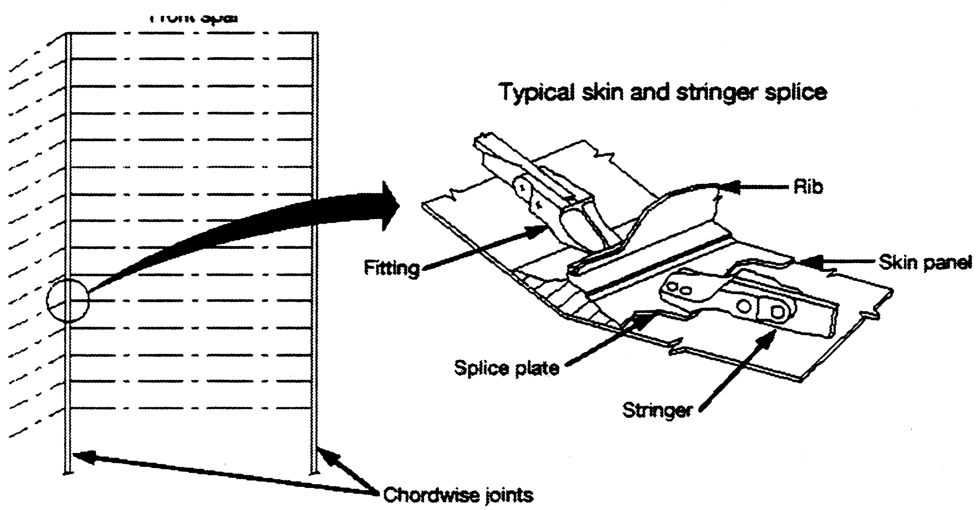
Figure 5.12 Latches and Hinges of Non-plug Doors (MSD/MED)



Type and possible location of MSD/MED
- MSD—cracks initiated at multiple critical fastener holes in skin at runout of doubler

Service or test experience of factors that influence MSD and/or MED (examples)
- High load transfer—high local stress

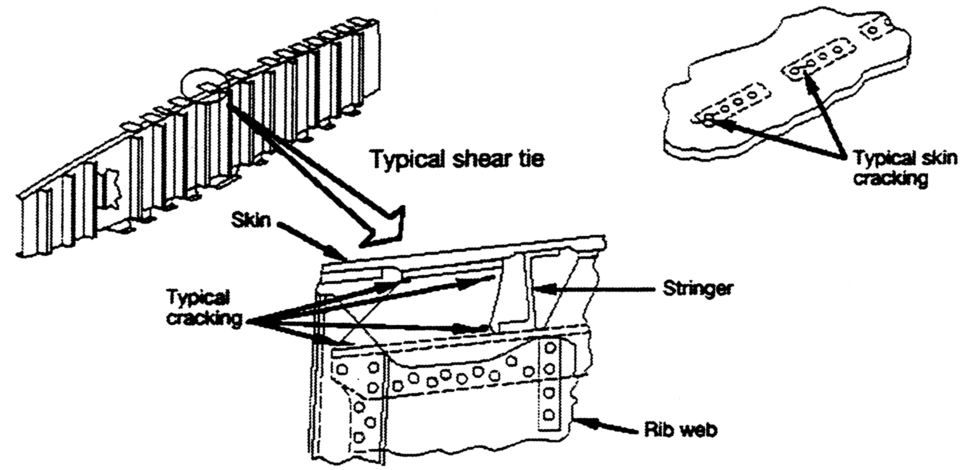
Figure 5.13 Skin at Runout of Large Doubler (MSD) Fuselage, Wing or Empennage



Type and possible location of MSD/MED
- MSD—skin and/or splice plate
  - Chordwise critical fastener rows
- MED—stringer runout of fitting
  - Fatigue-critical fastener holes at stringer and/or fitting

Service or test experience of factors that influence MSD and/or MED (examples)
- High load transfer
- Local bending

Figure 5.14 Wing or Empennage Chordwise Splices (MSD/MED)



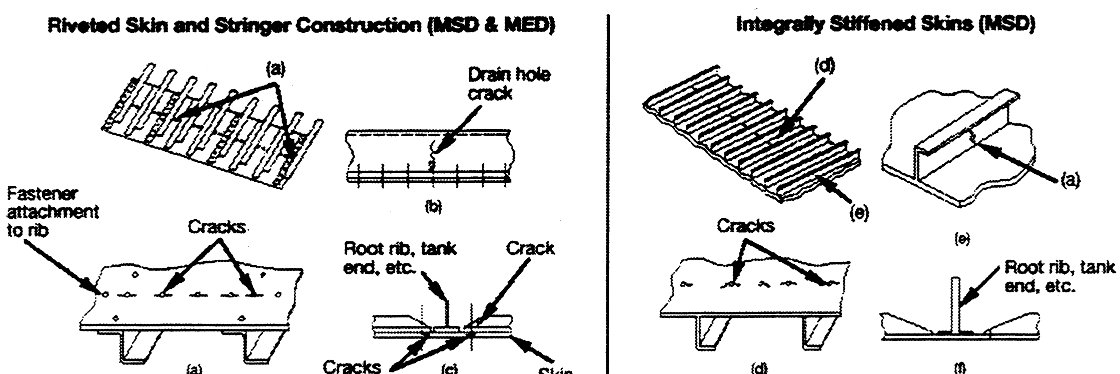
Type and possible location of MSD and MED

- MSD—critical fasteners in skin along rib attachments
- MED—critical rib feet in multiple stringer bays (particularly for empennage under sonic fatigue)

Service or test experience of factors that influence MSD and MED (examples)

- Manufacturing defect—prestress due to assembly sequence
- Sonic fatigue (empennage)

Figure 5.15 Rib to Skin Attachments (MSD/MED)



Inherent fail safe and crack stopper characteristics

- MSD—chordwise cracks link up at
  - a) Rib attachment holes
- MED—
  - b) Drain or vent holes
  - c) Stiffener run-outs at root rib or tank end rib

Do not have inherent crack stopper characteristics of riveted skin and stringer construction

- MSD—Chordwise cracks link up at
  - d) Rib attachment holes
  - e) Drain or vent holes
  - f) Stringer run-outs at root rib or tank end rib
- MED—becomes MSD

Figure 5.16 Typical Wing and Empennage Construction (MSD/MED)

5.3 DSD COMBINED WITH MSD

5.3.1 Background

In the AAWG report of 1993 Reference [3], a requirement for the consideration of Discrete Source Damage (DSD) was included within the proposed guidelines for the evaluation of WFD, as follows:

> *'If applicable, each WFD susceptible area should be evaluated for a discrete source damage event due to uncontained failure of engines, fan blades and high energy rotation machinery. If the risk due to such an event is not acceptable for the specific area, the characteristic WFD parameters, fatigue crack initiation, MSD/MED propagation, and occurrence of WFD should be evaluated to include this damage source.'*

Of the different types of DSD, only rotor burst was considered. This damage is the only one that could potentially result in scenarios that could interact with MSD/MED. Debris from a high energy event such as an uncontained engine failure has significant potential to degrade the residual strength of structural details susceptible to WFD. Other types of DSD, such as bird impact, do not have the same potential.

The risk due to such a combined event was quantified by the AAWG-TPG for several pre- and post-amendment 45 airplanes, and compared to the required levels in the airworthiness regulations. Six airplane types were included in this study, *viz.*

- Airbus A340
- BAC One-Eleven
- Boeing 727
- Boeing 737
- Boeing DC9/MD-90
- Lockheed L-1011

The results of these comparisons indicate that the generalized combined probability of failure is significantly below that required by the applicable regulations.

5.3.2 Technical Approach

Compliance with the current airworthiness regulations covering uncontained engine failures is demonstrated through two different parts of the Federal Aviation Regulations (FAR) and the Joint Aviation Requirements (JAR). In FAR/JAR 25.1309 References [5,6], system failures are assessed through the principle that there should be an inverse relationship between the severity of the effect of the failure on the airplane and the probability of its occurrence, *i.e.*

> *'(b) The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that*
> *(1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable; and*
> *(2) The occurrence of any other failure condition which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.'*

In the supporting Advisory Material, the probability of an extremely improbable failure condition is required to be not greater than 10^{-9} per flight hour, whilst the improbable failure condition has a probability not greater than 10^{-5} per flight hour.

Alternatively, FAR/JAR 25.903 References [7,8] calls for a safety analysis which considers the possible trajectory paths of engine rotor debris relative to critical areas, including damage to primary structure such as the pressure cabin, engine mountings and control surfaces. The rotor debris is modeled as a 'single one-third piece of disc', *viz.*

> *'It should be assumed that the one-third piece of disc has the maximum dimension corresponding to one-third of the disc with one-third blade height and an angular spread of ±3 degrees relative to the plane of rotation of the disc.'*

There is an additional requirement to consider small pieces of debris with an angular spread of ±5 degrees. The AAWG chose to encompass this requirement by considering the one-third piece of disc with an angular spread of ±5 degrees.

In order to demonstrate compliance with this regulation, it must be shown that, in the event of an uncontained engine failure, the risk of a catastrophic structural or systems failure is maintained at some acceptable level, *i.e.*

> *'When all practical design precautions have been taken and the safety analysis made using the engine failure model ... shows that catastrophic risk still exists for some components or systems of the airplane, the level of catastrophic risk should be evaluated. It is considered that the objective of the requirement will have been met if ... there is not more than a 1 in 20 chance of catastrophe resulting from the release of a single one-third piece of disc.'*

There is also a requirement in FAR/JAR 25.571, References [7,8], for the consideration of DSD. However, this regulation does not require consideration of environmental, fatigue or accidental damage in combination with DSD. In the past, regulators have normally accepted static analysis of the remaining structure, involving a 'scalping' cut from rotor debris passing through the structure, as demonstrating compliance with this rule.

In this assessment, the safety targets of 10^{-9} probability of failure per flight hour (FAR/JAR 25.1309) and 1 in 20 chance of catastrophe (FAR/JAR 25.903) have been selected to show compliance with the regulations.

5.3.3 Analytical Procedure

5.3.3.1 10^{-9} Probability of Failure per Flight Hour

Of all structural configurations, the most critical engine/airframe configuration with respect to the problem of DSD (e.g. potential damage) is that of a rear fuselage mounted engine. For the purposes of this discussion, the MD-90, a twin-engined airplane with the engines mounted in the rear fuselage is used.

An assessment of uncontained engine failure which results in the probability of failure per flight hour is a combination of the following components:

(a)Uncontained engine failure

(b) Phase of Flight

(c) Number of critical disks

(d) Critical spread angle

(e) Trajectory

(f) Critical Time

Based on these components, the Normal probability for a catastrophic airplane failure following a rotor burst is in the order of $4x10^{-11}$ for the MD-90. This probability is calculated in consideration of the following airplane/systems analysis

- Airframe Structure
- Avionics/Instrumentation
- Electrical
- Remaining engine
- Fire Protection
- Flight Controls
- Fuel System
- Hydraulics
- Pneumatics
- Multi System (worst case)

With the computation of a value less than $1x10^{-9}$, any possible interaction of MSD/MED with a discrete source event is non-existent based on today s regulatory standards.

5.3.3.2 1 in 20 Risk of Catastrophe

In the 1 in 20 calculation it is assumed that the uncontained engine failure event will occur, such that the probability of failure, P_{UEF}, becomes 1.0. The computation of the 1 in 20 risk of catastrophe involves the evaluation of the average risk from the phase of flight, spread angle, and trajectory. For the MD-90, the overall average risk, not considering the presence of MSD/MED is on the order of 0.04500 or 1 in 22.

The incremental effect of the possible presence of MSD/MED on this risk is computed considering the probability of the presence of MSD/MED, phase of flight, spread angle, and trajectory. The estimated total probability of having MSD/MED on an airplane being operated in the neighborhood of it s DSG is about 0.02 (based on a lognormal distribution with a standard deviation of 0.15). The total risk is given by:

R = 0.045 + 0.02*0.045 = 0.0459 or still about 1 in 22

This computation is conservative, based on the fact that if actual spread angles and trajectories were used for the threat of MSD, then the 0.045 would be somewhat reduced. Operation of the airplane would be permissible up until there was a total probability of MSD/MED of about 0.11. This would equate to around a 30% increase in the given DSG without impacting the 1 in 20 certification limit.

5.3.4 Environmental and Accidental Damage

The computations of the previous section were limited to a rotor burst scenario. There are other potential sources of damage that could lead to large-scale damage in the presence of MSD or MED. These include environmental degradation and accidental damage (including manufacturing damage).

As a result of the aging airplane activities started in 1988, maintenance programs have been modified to include corrosion prevention and control programs that effectively limit the amount of environmental degradation that can occur between maintenance visits. As part of the recommendations of this report, one element of an effective program to limit potential interaction between MSD/MED and environmental degradation is an effective corrosion control program. With this in place, a potential interaction between MSD/MED and environmental degradation is minimized.

Accidental damage, excluding obvious damage inflected on the ground, can be separated into two separate categories of events. The first type of accidental damage is that that might be caused by a dropped tool or other object, creating some significant but undiscovered damage to the structure. Maintenance programs are generally structured to find such events before they become critical through current scheduled inspections of the SSID or ALI program. This kind of damage is considered as local isolated damage and in general will never interact with MSD/MED damage scenarios. The other form of accidental damage is more of a concern since it in itself can be the source of MSD type events. This form of damage is the result of unapproved methods and procedures used either during manufacturer or maintenance. Damage such as scribe lines placed into structure while trimming adhesives or chemical milling masks are typical of the types of concerns this threat poses. There have been several notable in-service failures associate with this kind of damage. Unfortunately there is no way to predict the occurrence of this kind of damage. When this type of damage is found, it must be aggressively investigated and corrected on all airplanes that could be affected. The inherent fail-safe qualities of the structure should be more than adequate to contain this type of damage if the two-lifetime fatigue test rule is applied.

5.4 CERTIFICATION STANDARDS

Airplanes have been certified to a variety of standards over time with regards to damage sizes considered for residual strength evaluation. These standards have included:

- CAR 4b.270 (b)
  Ref. CAR 4b.270 (b), 1962:
  Fail safe strength. It shall be shown by analysis and/or tests that catastrophic failure or excessive deformation, which could adversely affect the flight characteristics of the airplane, are not probable after fatigue failure or obvious partial failure of a single principal structural element.

- FAR 25.571 Pre Amendment 45
  Ref. FAR 25.571 (c), 1967:
  Fail safe strength. It must be shown by analysis, tests, or both, that catastrophic failure, or excessive deformation, that could adversely affect the flight characteristics of the airplane, are not probable after fatigue failure or obvious partial failure of a single principal structural element......

- FAR 25.571 Post Amendment 45
  Ref. FAR 25.571 (c), 1978:
  Damage Tolerance (fail-safe) Evaluation. The evaluation must include a determination of the probable locations and modes of damage due to fatigue, corrosion, or accidental damage. The determination must be by analysis supported by test evidence and (if available) service experience. Damage at multiple sites due to prior fatigue exposure must be included where the design is such that this type of damage can be expected to occur. The evaluation must incorporate repeated load and static analyses supported by test evidence. The extent of damage for residual strength evaluation at any time within the operational life must be consistent with the initial detectability and subsequent growth under repeated loads. The residual strength evaluation must show that the remaining structure is able to withstand loads (considered as static ultimate loads) corresponding to the following conditions:

- FAR 25.571 Post Amendment 54
  Ref. FAR 25.571 (b), 1980:
  Damage-Tolerance Evaluation. The evaluation must include a determination of the probable locations and modes of damage due to fatigue, corrosion, or accidental damage. The determination must be by analysis supported by test evidence and (if available) service experience. Damage at multiple sites due to prior fatigue exposure must be included where the design is such that this type of damage can be expected to occur. The evaluation must incorporate repeated load and static analyses

supported by test evidence. The extent of damage for residual strength evaluation at any time within the operational life must be consistent with the initial detectability and subsequent growth under repeated loads. The residual strength evaluation must show that the remaining structure is able to withstand loads (considered as static ultimate loads) corresponding to the following conditions:

Both CAR 4b.270 (b) and FAR 25.571 Pre-amendment 45 require the applicant to consider that the failure or obvious partial failure of a single principle structural element would not be catastrophic to the airplane. Historically, these fail-safe damage sizes were related to large areas of structure being removed with positive static margins of safety with respect to 80% (CAR 4b and 100% FAR 25.571 Pre-Amendment 45) limit loads. The amount of structure removed was generally determined by a subjective criterion, namely that the structural failure or obvious partial failure represented by the structure removed would be easily detected and repaired before failure of the remaining structure.

The advent of fail-safe designs was a major step towards improved structural reliability and safety. However the fail-safe philosophy was not without its shortcomings. One of those shortcomings was made manifest in the crash of a 707 where a fail-safe load path failed leading to the loss of structural integrity of the horizontal stabilizer. As a result, the regulations regarding fail-safe structure were changed in 1978 through an amendment to FAR 25.571. This amendment (Amdt. 45) introduced certification requirements using damage tolerance concepts. At the time, this was deemed a significant technological advance since directed inspections were introduced to find and repair damage before loss of structural integrity could occur.

When the regulations were changed in 1978, the intent of 25.571 was also changed seemingly obscuring the requirement to design multiple load path, fail-safe structure. The damage tolerance evaluation recommended by AC 25.571 encourages applicants to consider these fail-safe concepts in the design. The two design philosophies, while broadly embracing the concept of allowing the structure to tolerate significant damage, differ significantly in how the capability is proven. Fail-safe methods employ the uses of ultimate strength capabilities of the structure with area out, whereas damage tolerance methods use yield strength or fracture toughness material properties. The damage capability of the structure demonstrated by one method generally does not have any comparison with the damage capability that might be determined using the other method.

While the requirements for initial certification require a damage tolerance evaluation, they normally do not require consideration of pre-existing fatigue damage including MSD and MED. These forms of damage are generally ruled out through the use of fatigue test evidence. The existence of MSD or MED fatigue cracks that might occur later in the service life of the airplane are of a considerable concern because they can affect the damage-tolerance damage sizes that the airplane is capable of sustaining.

5.4.1 Fail-Safe Analysis Damage Sizes

The 'fail safe' philosophy of Damage Tolerance used in the original certification relied on a static analysis with certain structural elements failed or partially failed. The 'failed' elements were assumed to carry no loads and the remaining, 'intact' structure was shown to be able to sustain a fail safe load level using a static structural analysis. The analysis assumes that there are no active cracks. The damage size chosen for this analysis was qualitative and was not specified by the regulations. The damage size chosen was large and considered 'conservative' to allow reliance primarily on general visual inspection (i.e. obvious partial failure). This allowed safe operation up to fail safe load levels until the damage was detected and repaired. Damage due to discrete sources, such as rotor burst, is also analyzed in this manner.

5.4.2 Damage Tolerance Analysis Damage Sizes

The damage tolerance approach utilizes crack growth analysis from an initial flaw size, to a critical crack length where limit load can just be sustained in the presence of an active crack tip. The requirements for damage tolerance certification are met when the applicant demonstrates that the inspection program developed as a result of the damage tolerance analysis will reliably detect a crack before it reaches the critical crack length.

The damage tolerance damage size is equivalent to the critical crack size. This damage size is highly dependent on a number of things including environment, material, design configuration, and structural loading. In general, applicants have a good deal of latitude in specifying the damage size on a case-by-case basis. Some applicants may not utilize the full residual strength capability of the structure in order to provide some level of conservatism in the inspection programs. In addition to fatigue related inspection programs, the structure is also inspected to detect corrosion and accidental damage

5.4.3 Survey of Certification Damage Size

Recently there has been a debate ongoing in the industry about how airplanes were certified to meet the fail-safe and damage tolerance requirements. The debate surrounds the damage sizes the industry used in the certification process. Two actions were taken by the AAWG to clarify this issue.

The AAWG tabulated damage sizes used in the certification analysis submitted by three different manufacturers. Each airplane had a different fail-safe/damage tolerance certification basis. The maximum damage size for each analysis location reported has been tabulated and plotted in order of descending crack size on the following figures:

Figure 5.4.3.1	Pre Amendment 45 (CAR 4b.270 (b))
Figure 5.4.3.2	FAR 25.571 (c) Post Amendment 45
Figure 5.4.3.3	FAR 25.571 (b) Post Amendment 54

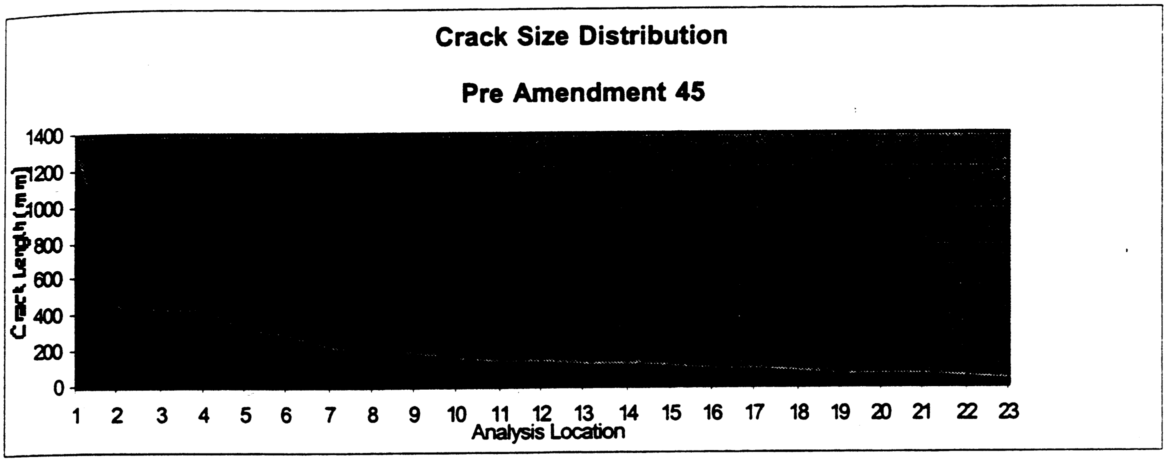


Figure 5.4.3.1 — Crack Sizes Used in Certification, Pre Amendment 45

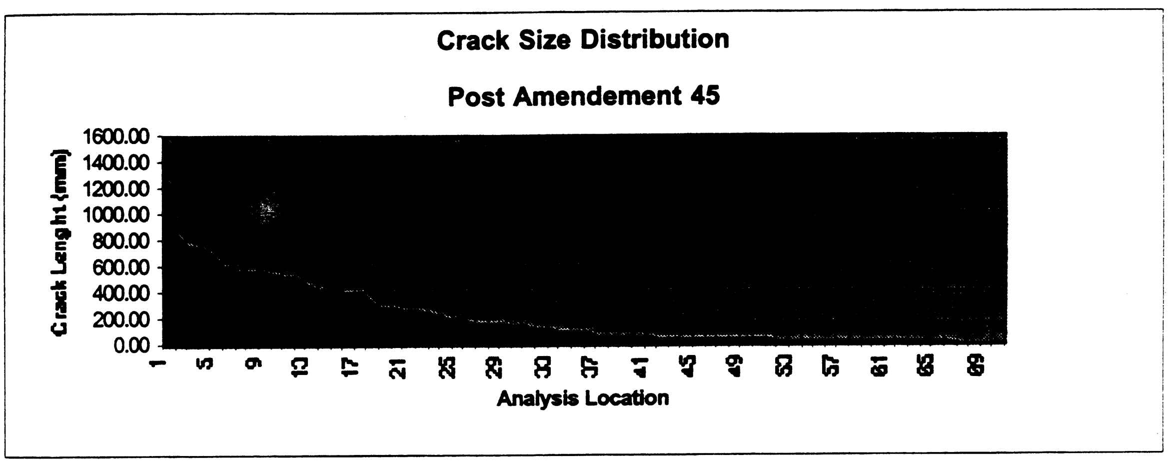


Figure 5.4.3.2 — Crack Sizes Used in Certification, Post Amendment 45

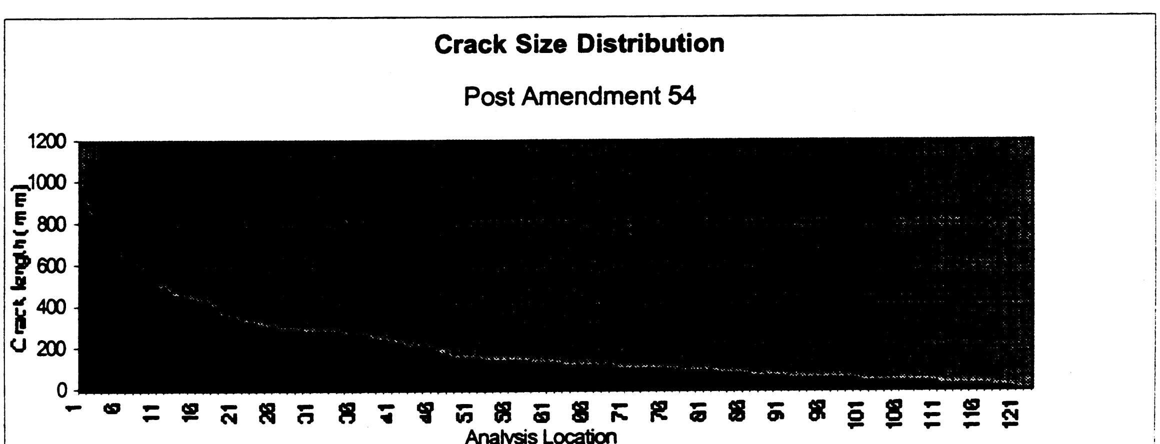


Figure 5.4.3.3 —Crack Sizes Used in Certification, Post Amendment 54

The following observations are drawn from review of these data:

- Charts are representative of industry practice for certification.
- Distributions are similar but independent of certification standards used.
- There is no typical damage size used in certification by the industry or required by the regulators.
- Damage size is highly dependent on location, design detail, and materials used.

5.4.4 Safety Enhancements

Airplanes certified prior to FAR 25.571 amendment 45 had supplemental inspection programs (SSIP) mandated by airworthiness directives. The SSIP programs effectively provided similar inspection programs to the inspection programs for airplanes certified post amendment 45. Since 1978, a number of new and innovative programs have been introduced that have enhanced the safety of the fleet for both pre- and post-amendment 45 airplanes. These programs include:

- Mandatory Modification Programs
- Corrosion Prevention and Control Programs
- Repair Assessment Programs
- SSID Revisions for obvious damage

These programs provide an increased level of surveillance. The increased level of surveillance, required by each of these programs at the airplane level, decrease the risk of having undetected structural degradation in high time airplanes with the net result of increasing safety within the fleet. While none of the programs is uniquely aimed at widespread fatigue damage, all have some inherent ability to detect MSD/MED before it becomes WFD.

New certification programs require the development of similar programs as part of the certification process in compliance with FAR 25.1529.

5.4.5 Conclusions

Over the past 20 years the regulatory certification requirements have shifted from a static strength fail-safe approach, comparing limit loads with ultimate static allowables, to damage tolerance evaluation comparing limit loads and fracture toughness. The fail-safe philosophy relies upon detection of obvious partial damage by routine inspections, whereas, damage tolerance relies upon directed inspections to detect smaller damage.

Review of the fail-safe/damage tolerance regulations, advisory material and the certification basis for numerous airplane models confirms that a FAA requirement that defines certification damage size does not exist. Certification damage size has always been subject to negotiation between the manufacturer and the regulator.

A common misconception is that all-primary structure has been certified using the classic fail-safe criterion of a two bay skin crack with a failed intermediate member being able to sustain limit load. In many cases this was an obtainable goal for fuselage structure designed by cabin pressure only, but the survey of certification damage sizes in section 5.4.3 shows this criteria was not necessarily applied for structure designed by the combination of flight loads and cabin pressure.

Damage tolerance critical crack criteria comparing limit loads to fracture toughness (active crack tip) should always result in a smaller critical damage size than a fail-safe criterion comparing limit loads and ultimate static allowables. The fact the current damage tolerance damage sizes are similar to prior fail-safe damage sizes is a tribute to the analysis and testing that has been done to increase the residual strength allowables.

There have been proposals within the industry that the original certification basis for an airplane model should be maintained in the presence of MSD/MED. This position with respect to certification damage size is unrealistic for two reasons. First, reanalysis of the structure using the current methods and fracture toughness allowables is likely to result in smaller allowable damage sizes than the old static strength based fail-safe analysis. Second, the presence of MSD/MED in the proximity of the crack tip can reduce the residual strength an additional 5 to 30%.

Whereas the original fail-safe criterion relied upon the detection of obvious partial damage by routine inspections the potential presence of MSD/MED will require directed detail inspections to maintain airworthiness.

5.5 MANAGEMENT OF MSD/MED IN THE FLEET

Since Aloha, known cases of multiple site damage/or multiple element damage have been effectively managed initially through implementation of mandatory inspections analogous to the monitoring periods recommended in Chapter 4.4. The inspection programs were typically implemented by the issuance of airworthiness directives by the regulatory authorities, or by alert service bulletins released by the OEM s. Monitoring periods are considered essential for safety management during the precursor stages (MSD/MED sources) of widespread fatigue damage, until terminating actions have been validated and implemented. Chapter 9.2 presents a detail discussion of the factors influencing lead times, which are necessary for effective long term WFD prevention. Interim safety measures via mandatory inspections are imperative to ensure safety as WFD-prone areas are identified by test, analysis, and/or service history and terminating modifications are accomplished. Monitoring periods should not be considered alternatives to terminating actions, but are deemed to be essential elements of the over-all WFD safety management plan.

5.6 SUPPLEMENTAL TYPE CERTIFICATES

5.6.1 Background

To understand the scope and magnitude of the supplemental type certificate problem, the AAWG obtained a copy of the *Summary of Federal Aviation Administration Supplemental Type Certificates*, published by the FAA in January 1998. From this list, a database of major alterations to principal structural elements was extracted (Appendix E), and sorted by OEM and airplane model. Broad categories of structural alterations that could affect, alter or nullify recommended OEM widespread fatigue damage audits were then identified.

5.6.2 Discussion

The majority of structural STC s with WFD concerns can be grouped into the following categories:

- Passenger-to-freighter conversions (including addition of main deck cargo doors).
- Gross weight increases (increased operating weights, increased zero fuel weights, increased landing weights, and increased maximum take-off weights).
- Installation of additional fuselage cutouts (passenger entry doors, emergency exit doors or crew escape hatches, fuselage access doors, cabin window relocations).
- Complete re-engine and/or pylon modifications.
- Engine hush-kits and nacelle alterations.
- Wing modifications such as the installation of winglets or changes in flight control settings (flap droop), and alteration of wing trailing edge structure.

Many of these STC s also include companion operational mission changes affecting original OEM load/stress spectrums.

Some STC s were found to have changed large areas of fuselage from externally visually inspectable structure to hidden details. Reliance on operator s baseline maintenance program visual inspection requirements may be critical elements of OEM WFD audits, especially during the reliance on monitoring periods to validate analysis or test MSD/MED source predictions. STC s may invalidate these safety management service action assumptions; and would require additional WFD analysis and/or testing. STC s that change baseline maintenance requirements such as frequency of detail visual inspections, or other inspection methods must be evaluated with respect to OEM WFD safety management programs. STC s must be reviewed to account for differences with the OEM baseline maintenance program requirements.

STC alterations creating or affecting principal structural elements must be evaluated to demonstrate the same confidence level as the original OEM structure. This confidence level must be equivalent to that obtained by a two DSG full-scale fatigue test without evidence of MSD/MED occurring in the STC affected structure.

All models identified by AAWG, as candidate WFD assessment fleets had STC changes affecting primary structure, since entering service. A listing of STC s compiled from the January, 1998 edition of the Summary of Federal Aviation Administration Supplemental Type Certificates that could appreciable affect OEM WFD audits of principal structural elements are given in Appendix E. Note: This list contains only modifications accomplished on more than one airplane, single airplane STC alterations are not included.

5.6.3 Recommendations

All STC s affecting primary structure should have widespread fatigue damage assessment. The AAWG recommends that the following criteria be used for determination of which STC design characteristics and features would require widespread fatigue damage assessment:

- Major alteration to airplane structure in which a new or modified principal structural element (PSE) is created.

  Example: Freighter conversion with the addition of an outward opening, hoop tension main deck cargo door and door surround structure. The main deck door and door surround structure are new PSEs.

- Major alteration to airplane structure in which the alteration was not certified to damage tolerance requirements.

  Example: Freighter conversion with the addition of an outward opening, hoop tension main deck cargo door with certification prior to application of FAR 25.571, Amendment 45 (pre-1978), or those STC s that have not had structural reassessments to damage tolerance standards (and do not have resulting supplemental structural inspection programs, *with consideration for WFD sources,* implemented).

- Major alteration to airplane structure that appreciably changes the load and stress distribution, load and stress magnitude, load spectra and stress history, stiffness, mission severity, adversely affects inspectability or continued airworthiness limitations of primary structure.

Example: Addition of a winglet to a wing that changes the wing center of pressure, stiffness and spectrum (and may introduce new failure modes).

- Major alteration to airplane structure that contains design features identified by AAWG as susceptible to sources (MSD/MED) of widespread fatigue damage (See Section 5.2).

Example: Freighter conversion adding fuselage plug with main deck cargo door with new skin joints, and hoop tension concentrated load path latch hooks on door surround structure.

5.6.4 Compliance Time for STC WFD Assessment

The compliance time for the widespread fatigue damage assessment on STCs affecting primary structure should be the same calendar compliance as the original structure. The FAA tasking statement for rulemaking and advisory circular activities should state clearly that STCs would be included in the final rulemaking. This statement would alert operators and STC holders of the forthcoming regulatory action, and would strongly recommend that the assessment programs begin (similar to actions already being undertaken by the OEM s for WFD assessment of the type design structure). This notification would give operators and STC holders approximately 3 years to complete the Engineering assessment necessary to meet any final rule requirements, assuming work was begun when the FAA WFD tasking statement was published in the Federal Register. Note: Establishment of design goals for STCs affecting primary structure will be required as part of the rule making activity to follow on from this tasking. Establishment of design goals for STCs will effect both existing and future STC modifications.

5.6.5 Summary

Supplemental type certificate alterations to airframe structure can appreciably affect, alter or nullify widespread fatigue damage programs developed by the OEM. Any comprehensive widespread fatigue damage safety management program must include airframe structure that has been altered by supplemental type certificates. Criteria have been established for determination of categories of STC alterations that must be assessed for widespread fatigue damage. WFD audit requirements for STCs should be the same standard and timelines as original model specific programs. STC alterations creating or affecting principal structural elements must be evaluated to demonstrate the same confidence level as the original OEM structure. This confidence level must be equivalent to that obtained by a two DSG full-scale fatigue test without evidence of MSD/MED occurring in the STC affected structure. Responsibility for completion of WFD audits on STCs will ultimately be the operator s (implemented by FAR 121 and/or 25.1529 rulemaking).

5.7 COMBINATION OF MSD/MED SCENARIOS

The AAWG examined the issue of whether or not it was possible to have a simultaneous occurrence of MSD and MED in a single principal structural element. The AAWG concluded that there was a distinct possibility that this could occur on some details that were equally stressed. This scenario should be considered in developing appropriate service actions for a PSE should this event seem likely.

It is suggested that if an area is potentially susceptible to both MSD and MED, then both problems be worked independently. If the thresholds for both MSD and MED indicate a high probability of interaction, then this scenario must be considered.